INTERNATIONAL SEISMOLOGICAL CENTRE

2009

Annual Director's Report

The year 2009 has been another year of active and successful search for further financial support. New data, products and services were offered to users. Work on the CTBTO Link to the ISC database has begun. New members of staff have been trained and essential building maintenance has been carried out without an interruption to operations. The Centre received a lot of good publicity. It was another successful year in the history of almost half a century old organization.

CONTENTS:

EXECUTIVE SUMMARY

2009 has been another successful year for the ISC. Through the increased support from existing and new members and also an additional grant from the UK Foreign and Commonwealth Office and institutions in Nordic countries, the ISC's finances have been further improved. Two further grant applications to NSF and GEM have been submitted.

Three new members of staff were hired to work in operations and develop existing and new services that the ISC provides to seismologists and geophysicists worldwide. Training of new staff members as well as a large essential ISC building maintenance programme have been completed without interruption to services and development.

The EHB bulletin is now re-accommodated within the ISC Bulletin and also distributed by the ISC as a stand-alone product along with corresponding station arrivals. At the same time work has continued on improving the ISC own location procedures as well as, jointly with the CEA/DASE, on using automatic waveform analysis to constrain event depths.

Current reviewed bulletin collection from networks now stands at almost 12 months behind real time. The final ISC analysis stands at 24-25 months with intention to reduce it to 15-18 months in the coming years. In addition, to fill the time gap between seismic event occurrence and corresponding bulletin publication, the ISC collects reviewed preliminary data from many data centres around the world. This information arrives within days and weeks after event occurrence and is being grouped and distributed the next day after submission as part of the automatic preliminary ISC Bulletin.

To facilitate a more convenient access to both preliminary and final reviewed ISC Bulletin an interactive bulletin search tool was introduced on the ISC website.

A substantial progress was made on the project of providing the Link to the ISC database for CTBTO PTS and NDCs. This Link will help to establish the ISC as one of the essential providers of data for the monitoring community.

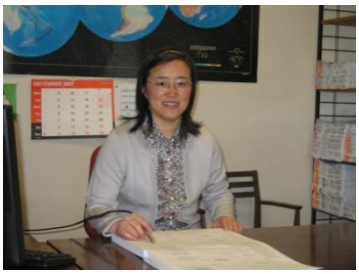
During the year further funds have been raised or committed by new and existing members to allow the development of the interactive editing tool, to further improve the entire ISC Bulletin and to introduce new services and products.

STAFF

OPERATIONS:

James Harris, *United Kingdom*,
System & Database Administrator

Beatriz Vera, *Colombia*,
Seismologist / **Lead** Analyst



Baokun Li, *China*, Seismologist / Analyst,
left in October

Elizabeth Robertson, *New Zealand*,
Seismologist / Analyst, **arrived in March**

Emily Delahaye, *Canada*, Seismologist /
Analyst, **arrived in September**

Shengzao Chen, *Canada/USA*,
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Maureen Aspinwall, *United Kingdom*,
Administration Officer

OPERATIONS

INTERNATIONAL SEISMOGRAPHIC STATION REGISTRY

Traditionally the ISC maintains the International Seismographic Station Registry (IR) together with the World Data Center for Seismology, Denver (NEIC). The IR allocates globally unique codes to seismic stations and currently has over 17.5 thousand stations registered. Those stations that have reported to the ISC for data year 2007 are indicated on figure 1 in red. The ISC runs a popular web-page allowing review of already registered stations as well as submission of parameters required to register a new station. Valuable assistance has been received from IRIS during the process of registering and updating coordinates of the USArray stations. Station codes for projected sites of the Transportable Array have been initially reserved for future use without specifying exact coordinates. During the actual installation process some sites often shifted some distance in search for better local geological and noise conditions. Once re-measured these coordinates are fully registered in the IR.

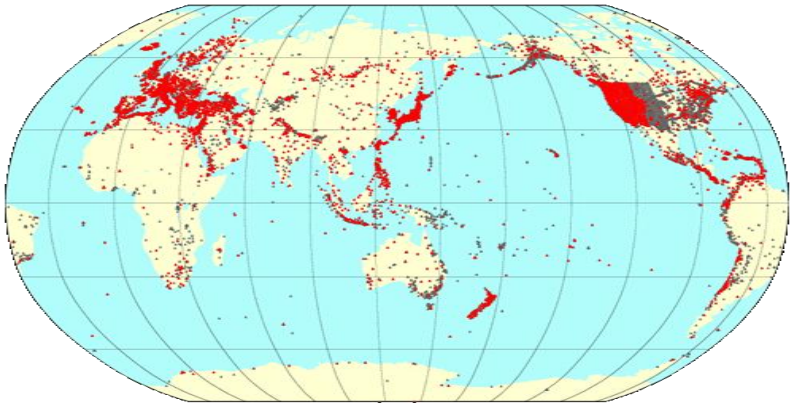

Figure 1. *17,524 stations, open or closed, are currently registered in the IR; 4981 of those (red) reported seismic arrival data to the ISC for data year 2007. USArray stations are integral part of the Registry.*

PRELIMINARY BULLETIN DATA COLLECTION, PRELIMINARY ISC BULLETIN

In 2009 the ISC continued improving its collection of preliminary bulletin data from various networks and data centres. These data are expected to undergo at least a minimal review by local analysts. Typically these data include a preliminary hypocentre location, magnitude estimate, moment tensor solution and station arrival data, though variations are large from agency to agency. As many as 21 agencies reported preliminary data to the ISC in 2009 (figure 2).

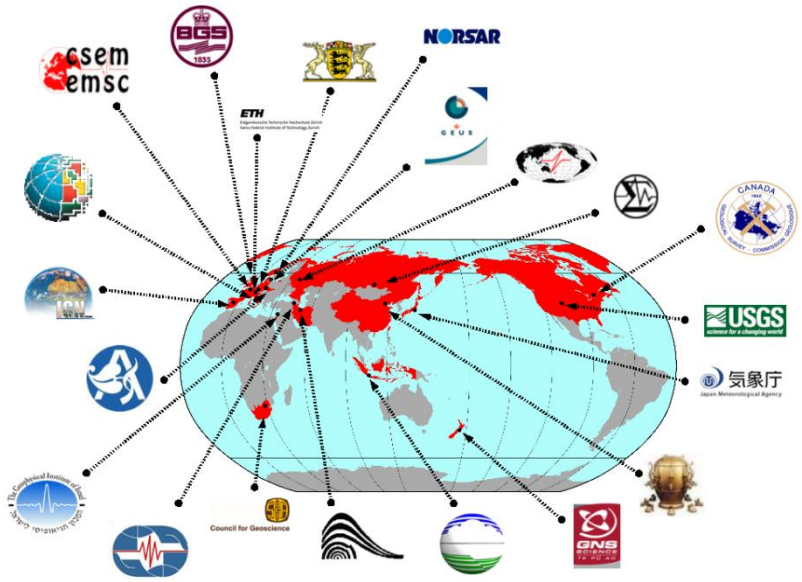

Figure 2. *21 networks and data centres report preliminary reviewed bulletin data to the ISC. These reportscover areascoloured in red. In addition, grey coloured areas are covered by reports from NEIC, EMSC, Geophysical Survey of Russian Academy of Sciences (GSRAS) and China Earthquake Networks Center (CENC).*

Preliminary hypocentre solutions and station arrivals are grouped in the ISC database within a day after receipt and made available through the standard ISC Bulletin search procedure. For each event an output includes several hypocentre solutions reported by various agencies, all reported source mechanisms and magnitude estimates as well as corresponding station arrival data. Each earthquake header includes logos of reporting agency. By clicking on the logo, Preliminary ISC Bulletin user could get further information from each agency directly.

Figure 3 shows the map and magnitude distribution of events reported to the ISC within 3 days, 7 days, 1 month and 4 months of occurrence. It appears from the graph that almost all events with magnitude 4.8 and above and many of smaller magnitudes are reported within the first week. Further reports beyond one week add information to already reported large and moderate events and also inform about smaller events.

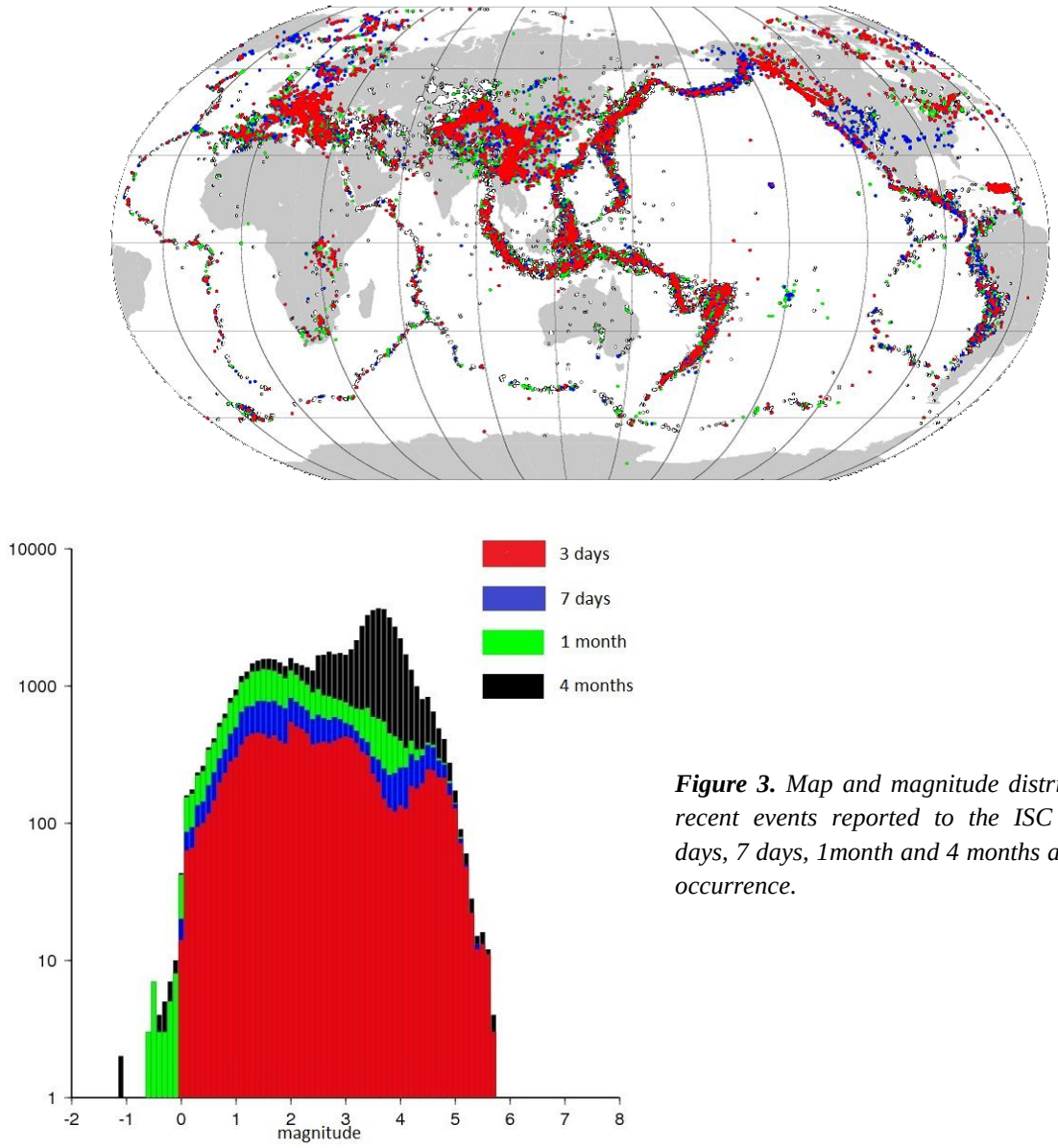

Figure 3. *Map and magnitude distribution of recent events reported to the ISC within 3 days, 7 days, 1month and 4 months after event occurrence.*

This additional initial data collection is intended to fill the gap between the event occurrence and the time when the final Reviewed ISC Bulletin becomes available. It presents an attempt to consolidate the effort of many data centres and networks to make their data available internationally in good time. At this stage ISC does not compute or publish its own event solutions. This service is not intended to be used by media or civil protection agencies. It is designed to be used by seismologists wishing to receive as much information as possible from one single place and then to get access to details using provided links to the original data reporters.

Obviously preliminary data from agencies are later substituted with their final bulletin data, well before the ISC analysts make their final review of the ISC Bulletin. The ISC hypocentre solutions are still based on the final set of bulletin data given by each reporter.

STANDARD BULLETIN DATA COLLECTION

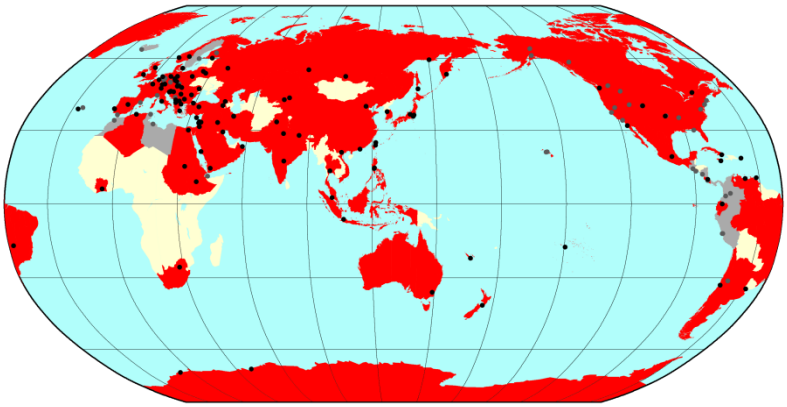

Figure 4. *Approximately 120 agencies around the world (black dots) report bulletin data directly to the ISC. Dry land territories covered by these reports are in red. Grey areas and grey dots indicate those territories and agencies that are covered indirectly via reports from NEIC, EMSC and CASC. Light colour indicates areas that are not covered by local network operator reports.*

The standard ISC data collection is the collection of final reviewed bulletin data from approximately 120 different agencies around the world. During 2009 we continued to reduce the delay in collection by 2.5 days per month on average. At the end of 2009 this delay stood at 12.3 months behind real time with all agencies (except for three) being able to cope with the schedule. In case of GNS (New Zealand), the delay is temporary and caused by the GNS trying to move bulletin production closer to real time at the expense of analysis of limited periods of time delayed until later. We hope that GII (Israel) and LGRB (Freiburg, Germany) would also be able to overcome difficulties and return to timely and prompt delivery of bulletins as was always the case in the past.

We plan to stop accelerating the data collection soon, once the schedule reaches the mark of 12 months behind real time. This delay would allow data contributors to have enough time for reviewing and finalising their bulletin data before submitting those to the ISC.

Figure 4 shows approximately 120 agencies that routinely report final reviewed bulletin data to the ISC. Red colour on this figure indicates those dry land territories that are covered by these reports. Grey colour indicates those areas that are indirectly covered via reports from NEIC, EMSC and CASC. It is clear that further work on improving the ISC data collection in Africa, South America and parts of Eastern Europe and Asia is required. Large events with magnitude 4.5-5.0 and above in Africa and on mid-oceanic ridges are reported by the National Earthquake Information Center (NEIC), International Data Centre (IDC/CTBTO), Geophysical Survey of Russian Academy of Sciences (GSRAS) and China Earthquake Networks Center (CENC).

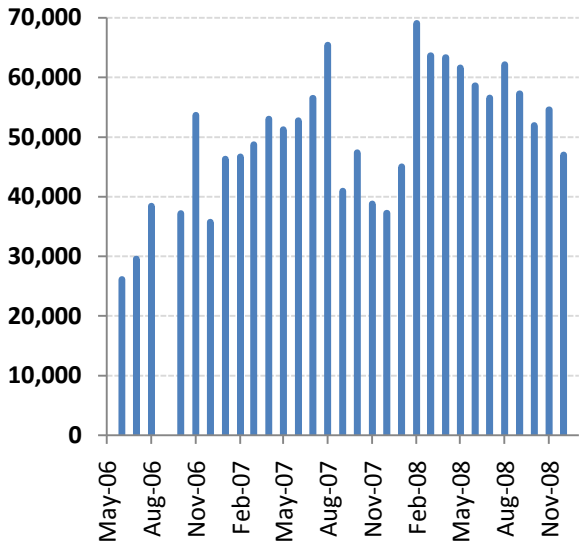

Figure 5. *Number of arrival picks reported by USArray stations for events in the ISC Bulletin per data month.*

During 2009, IRIS DMC continued its contribution of station arrival times that were picked and reviewed by USArray Array Network Facility in San Diego. The data set represents a considerable increase in station arrival numbers associated to already known events in the US and moderate to large events worldwide (fig. 5). Whilst being a major source of data for tomographic research, this data set presents a major challenge to the ISC:

- Current ISC location algorithm is not designed to cope with the bias caused by large concentrations of seismic stations in specific azimuthal directions
- Current ISC Bulletin review procedures are designed for analysts to review parameters of each station arrival. The increased numbers of stations reporting the same events present a challenge for the editing team.

During 2009, new bulletin data sets were received from the following institutions:

- National Survey of Seismic Protection, Yerevan, Armenia
- Centre of Geophysical Monitoring, National Academy of Science, Minsk, Belarus

An important advance was made by the CWB (Chinese Taipei). We have received all missing data from July 1, 2005 till present. In addition, the bulletin data were given to us in a new format that lists station arrivals for all events as opposed to only felt ones as was the case in the past. This will allow the ISC to improve location of many seismic events in the vicinity of Taiwan and Ryukyu Islands by simultaneously using arrival times at stations of CWB and JMA networks. On behalf of all ISC data users, we are grateful to CWB for this effort.

ISC BULLETIN REVIEW

The ISC seismologists/analysts review and correct results of automatic procedures that form and update the ISC Bulletin as the data from agencies arrive to the ISC. This is the analyst's review that makes the ISC Bulletin accurate and trustworthy.

The accuracy of ak135-based ISC solutions and magnitude estimates, proper grouping of reported information between the events in the bulletin is under constant scrutiny. The ISC

analysts also review the correctness of automatic association of reported station arrivals to events, reported arrival's phase identification and travel-time residuals. When the time comes, one month worth of data is pulled into separate table space, a set of automatic procedures run and first automatic ISC event locations and magnitude determinations are made for those events that are large enough to be reviewed by the ISC seismologists. It would be impossible for the ISC to sustain a review of every reported event, so from data year 1999 the data collection thresholds were removed and review thresholds introduced. Following various recent improvements this system continues to serve its purpose by restricting the number of seismic events to be reviewed by ISC analysts. The threshold criteria are complex yet almost all events of magnitude approximately 3.5 and larger are reviewed.

The team of four ISC analysts reviewed almost 12 months worth of the bulletin data during 2009. The team was also helped by the Director during the last steps in the analysis procedure.

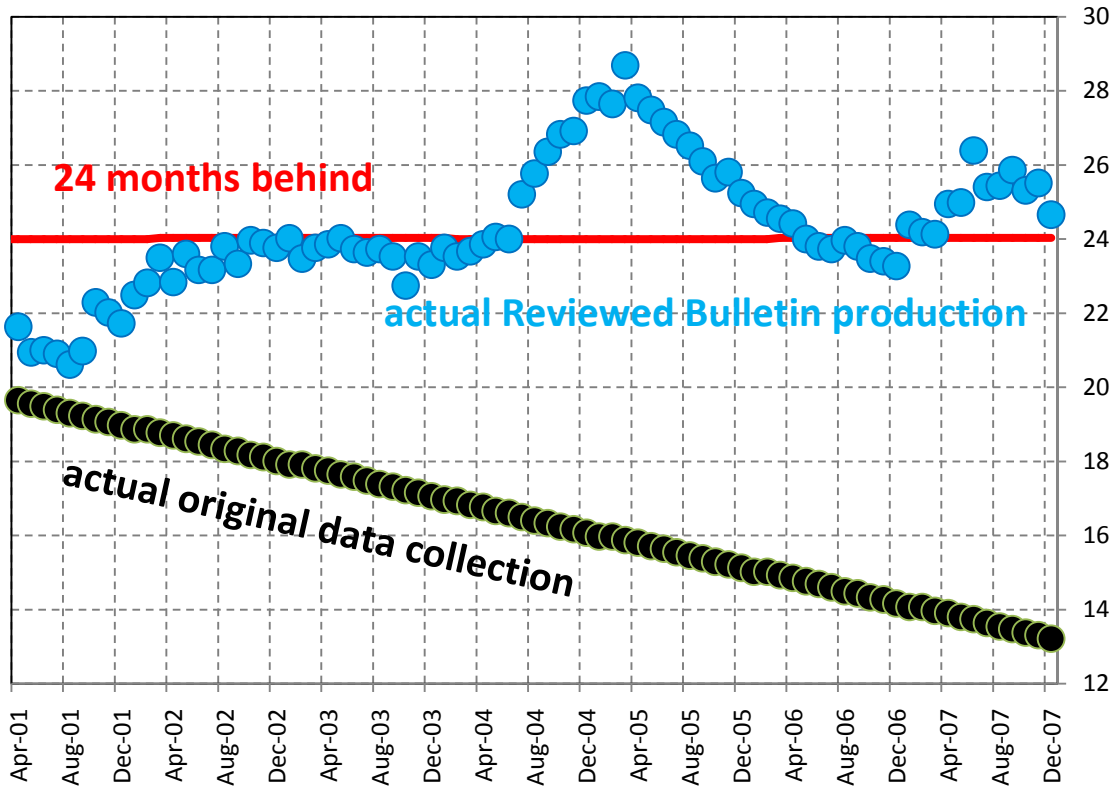

Figure 6. Timeliness of the standard ISC data collection and Reviewed ISC Bulletin production. X-axis indicates completed data months and the Y-axis shows the delay behind real time in months.

Year 2009 was especially challenging. One of the new analysts has arrived in March. In September, before the training was complete, two other new analysts arrived to be trained. One of the most experienced analysts finished her work at the ISC in October. This made its mark on the overall speed of analysis and Bulletin delivery times that were scattered between 24 and 26 months behind real time (fig. 6).

The other difficulty was ever increasing volumes of station arrival data currently reported to the ISC as compared to only 2.5 years ago. As explained above, the USArray arrival times play fair part in this increase. Since analysis procedures, used at the ISC to this day, require analysts to review travel-time residuals at all station arrivals, the load on analysts increased by as much as 60% in the last 2.5 years (fig. 7).

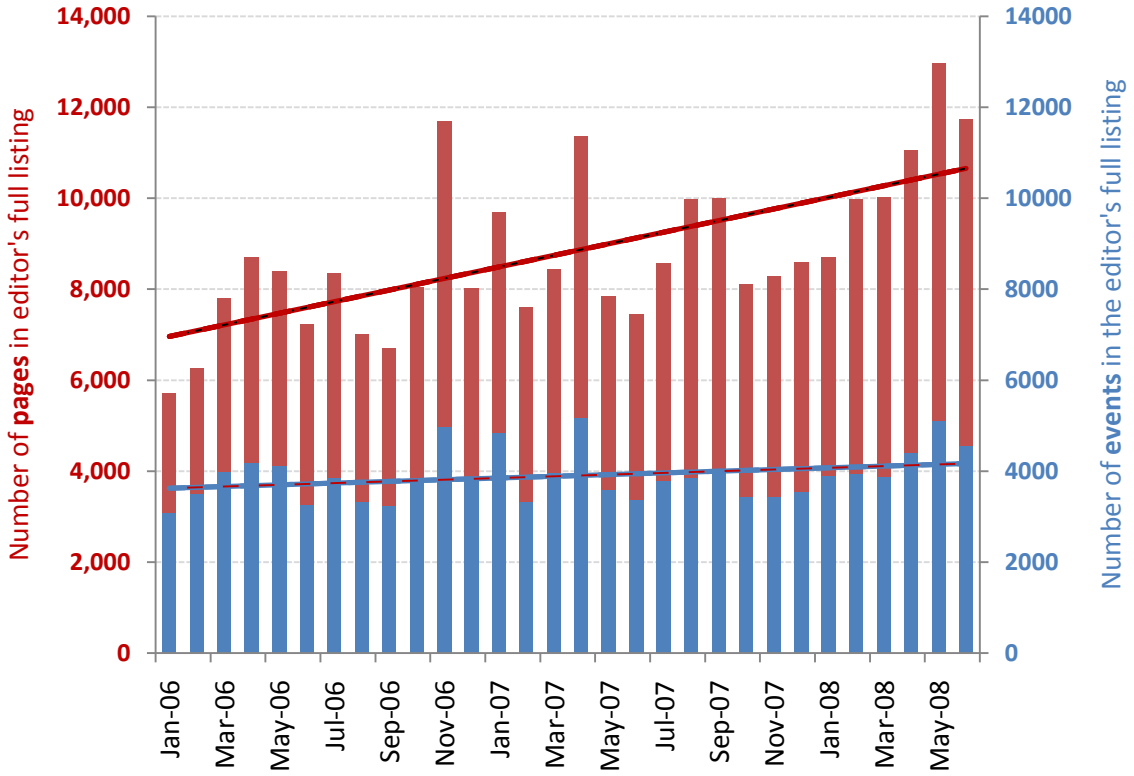

Figure 7. *The total number of reviewed events in the ISC Bulletin (blue) and the number of printout listing pages reviewed by the ISC analysts during the first most difficult pass (red) per month.*

It was recognised earlier that a new approach to the Bulletin review process is required. One of the answers is the introduction of an interactive editing system in place of the paper-based batch-type analysis. Also, the ISC needs to concentrate on the review of outliers instead of reviewing all data. Following the ISC Executive Committee decision we started reviewing our options in producing new analysis tools.

A post of computer programmer was advertised yet candidates who answered the advertisement were lacking necessary skills for the salary we could afford to offer. In addition, we made a number of approaches to private software companies to see if the task of building new software package could be outsourced. After a number of initial negotiations we arrived to a conclusion that a clear design and specification of the tool need to be put together at the ISC first. We ran a brain-storming meeting at the ISC and quite a few useful ideas and suggestions moved us forward. One of the former senior ISC seismologists with extensive experience of data analysis at the ISC and IDC also contributed to our meeting using the Skype link. It will probably take a few months before a clear design and specification

document for the first version of the software will become available. At this point a further decision will be made if a programmer is to be hired at the ISC or the project is to be outsourced to a software company.

IASPEI GT LIST

The International Seismological Centre maintains the IASPEI database of Reference Events (earthquakes and explosions) for which epicentre information is known with high confidence (to 5km or better (GT5)) with seismic signals recorded at regional and/or teleseismic distances. It should be noted that the depth of these events is not known to the same level of accuracy as the epicentre. The global effort of collecting and validating GT events was coordinated by the CoSOI/IASPEI working group on Reference Events for Improved Location chaired by Bob Engdahl and Paul Richards. This database of a significantly large number of reference events (over 7,000) (fig. 8) and approximately 500,000 station arrivals facilitates better visualization of the Earth structure, better modelling of velocities of seismic waves, more accurate travel time determinations and increased accuracy of event locations. ISC users are able to search this database at the ISC website and receive GT locations and corresponding ISC locations along with station arrival data available for each event. A cross-link to the ISC Bulletin is provided for users to go between ISC and GT databases. Figure 9 shows comparative numbers of nuclear explosions, chemical explosions and natural seismic events in each GT category.

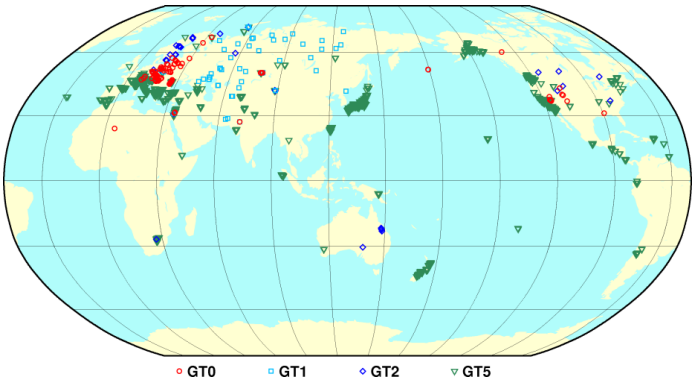

Figure 8. *Events in the IASPEI list of Reference earthquakes and explosions. Colours indicate the GT accuracy to which the position of epicentre of each event is known.*

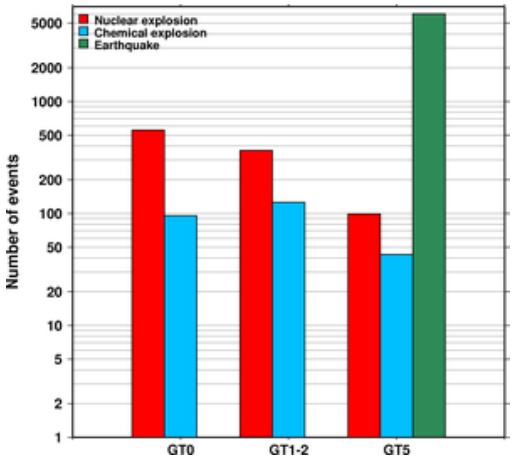

Figure 9. *Number of nuclear explosions, chemical explosions and natural earthquakes in each GT category.*

ISC WEB and FTP SERVICES

The ISC web-site as a whole and the ISC Bulletin search in particular continued to grow in popularity over 2009 (see figure 10). The number of hits (excluding web crawlers) reached 3.5 million, having increased 59% compared to year 2008. The number of Bulletin searches compared to 2008 went up by 50%.

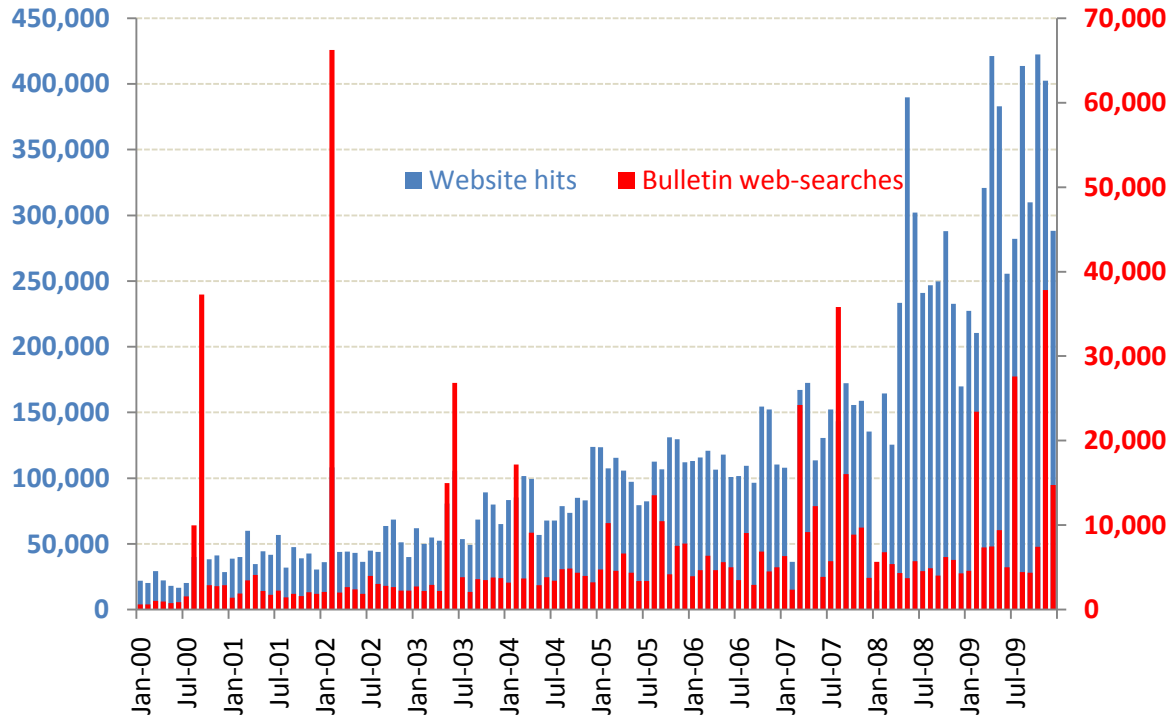

Figure 10. *Number of ISC website hits (blue, left axis) and number of ISC Bulletin searches (red, right axis) per month.*

The most popular services were (in the order of presentation):

- International Station Registry (up three times compared to 2008);
- Standard ISC Bulletin search, including EHB & GT datasets (50% up);
- Maps using the bulletin search data;
- Interactive ISC Bulletin search;
- Bibliography search;
- Links to agencies providing real time data;
- Search of original data contributed to the ISC.

The statistics of the ISC web-site use per country are shown on figure 11. Although .net, .edu and .com are the domains mostly registered in the US, they are shown separately. In any case the US is by far the largest user of our services followed by Russia, Italy, UK, France, Portugal and others.

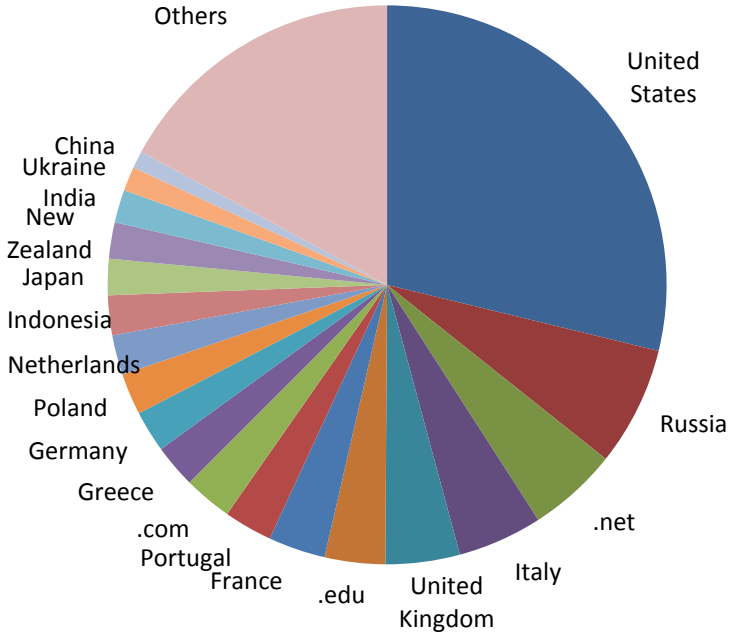

***Figure 11**. Usage of the ISC **web-site** per country, percentage of hits. Category "Others" includes all countries with a share of less than one percent.*

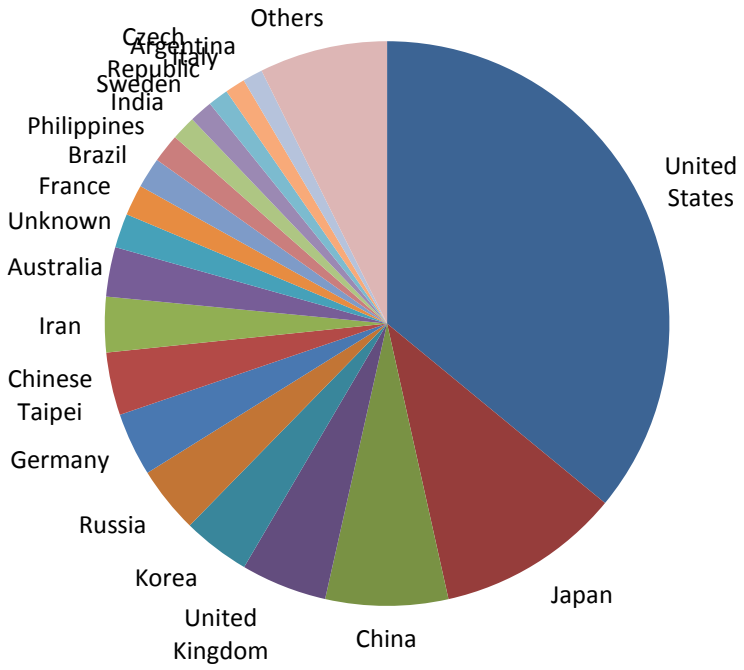

***Figure 12**. Usage of the ISC **ftp-site** per country. Category "Others" includes all countries with a share of less than one percent of total number of filestransferred.*

The statistics of the ISC ftp-site use per country is shown on figure 12. Again, the US is by far the main user of our ftp services followed by Japan, China, United Kingdom, Korea, Russia and others.

DEVELOPMENTS

EHB (Groomed ISC Bulletin)

The EHB (E.R. Engdahl, R.D. van der Hilst, R. Buland ,1998) catalogue contains a set of most accurate seismic event locations regularly used in academic research, especially in seismic tomography. The EHB algorithm has been used to significantly improve routine hypocentre determinations of well recorded events (fig. 13) made by the ISS, ISC and PDE.

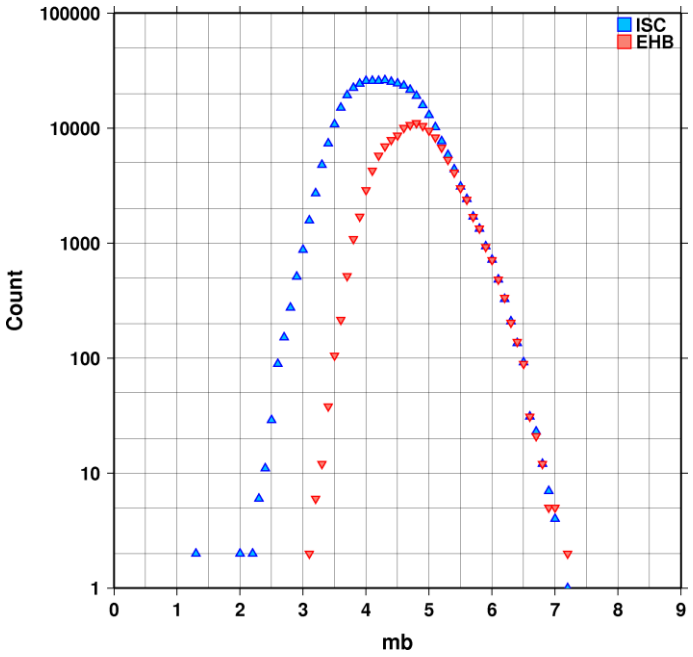

Figure 13. Comparative magnitude distribution of events in the ISC and EHB (groomed ISC) Bulletins.

The EHB algorithm uses:

- the ak135 1D global travel-time model with ellipticity and elevation corrections;
- iterative relocation with dynamic phase identification;
- first arriving P, S and PKP phases and teleseismic depth phases pP, pwP and sP;
- empirical teleseismic patch corrections (for 5x5 degree patches);
- weighting by distance-dependent phase variance;
- selection criteria for EHB events having 10 or more teleseismic ($\Delta > 28^{o}$) observations with a teleseismic secondary azimuthal gap < 180^{o}.

Following the agreement with Bob Engdahl, the EHB is now hosted on the ISC website and currently contains 130,000 events between 1960 and 2006 accompanied with ~20,000,000 arrival data. 2007 is currently in production. The bulletin is regularly updated by Bob Engdahl and made available to the ISC for inclusion into the ISC Bulletin and for re-distribution to all ISC users. The EHB can be browsed, search or downloaded from the ISC web-site. Corresponding events of the ISC and EHB Bulletins are cross-referenced for convenience of the ISC users.

INTERACTIVE ISC BULLETIN SEARCH TOOL

Users of the on-line ISC Bulletin are used to filling the form before getting out a limited set of ISC Bulletin data that they requested. The new interactive tool (fig. 14) is designed to work alongside with the standard tool (www.isc.ac.uk/search/custom/index.html) and allows users to choose the data in an interactive fashion using polygons drawn on a map. The output

of this search includes not only the extract of the ISC Bulletin but also the outcome of pre-defined queries allowing to show various types of seismic events, GT-events, source mechanisms, analyse magnitude relations, observe the evolution of the completeness magnitude through the years, analyse sequences and clusters of earthquakes, draw depth profiles and make comparisons of agency's solutions. One important feature of this tool is that one of the outputs includes those magnitude parameters that are considered by the ISC as best for each event. This feature is supposed to answer requests of those users who experienced difficulty in dealing with numerous magnitude estimates that are being reported by various agencies to the ISC and also reported as part of the ISC Bulletin.

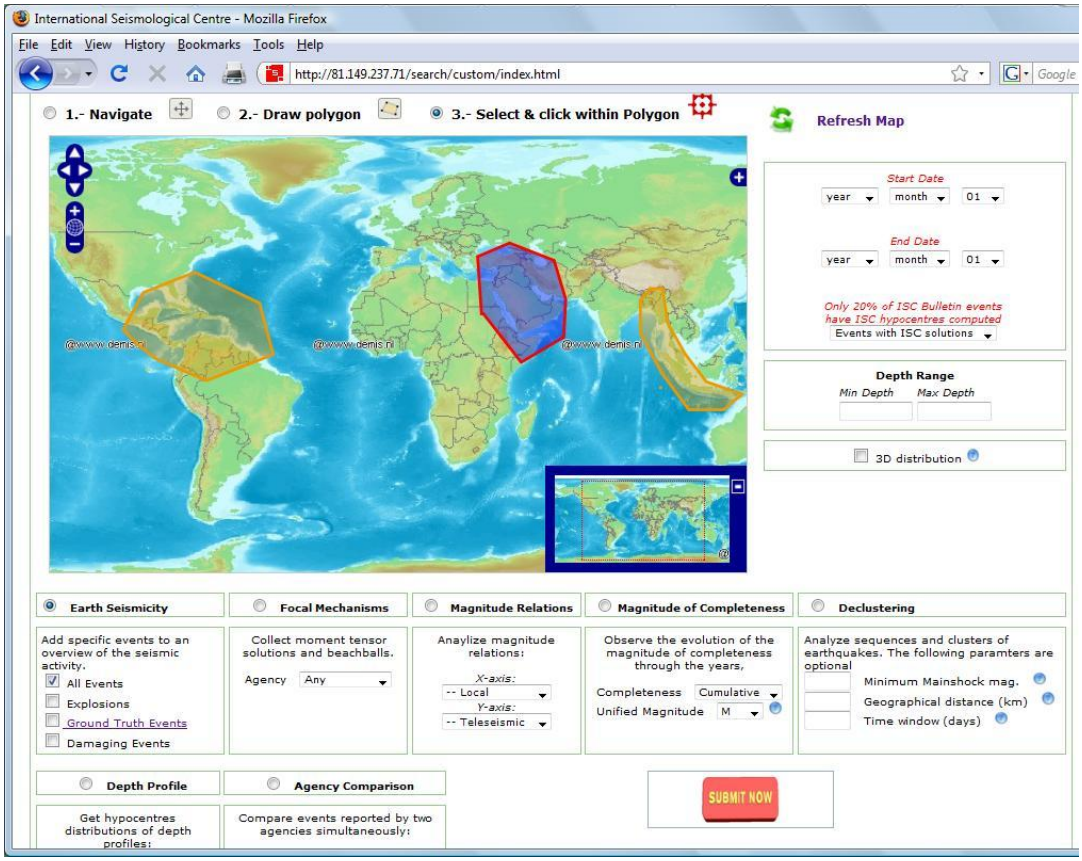

Figure 14. The front end of the Interactive ISC Bulletin Selection Tool.

PREPARING TO IMPROVE THE ISC LOCATION PROCEDURES

The first step in the process of modernizing the ISC location procedures was the adoption from data month of January 2006 of the ak135 velocity model for computing ISC hypocentres whilst still producing for long-term consistency an additional set of un-reviewed locations based on Jeffreys-Bullen travel time tables. Since mid-2008 the ISC was involved in developing new location algorithm that would ensure the best location results possible with 1D model on the global scale.

During the past year the coding of the new ISC location software has been finalized. The new ISC location algorithm

- Uses all *ak135* (Kennett et al., 1995) predicted phases (including depth phases) in location;
- Applies elevation, ellipticity (Dziewonski and Gilbert, 1976), and depth-phase bounce point corrections (Engdahl et al., 1998);
- Attempts free-depth solution only if there is depth resolution;
- If there is no depth resolution, the depth is fixed to a region-dependent default depth derived from either EHB (Engdahl et al., 1998) free-depth solutions, or where there is insufficient seismicity to obtain an EHB-based default depth estimate, from the CRUST2.0 global crustal model;
- Accounts for correlated model error structure;
- Obtains initial guess via nearest-neighbour grid search (Sambridge and Kennett, 2001);
- Performs iterative linearized inversion using *a priori* estimate of the full data covariance matrix (Bondár and McLaughlin, 2009a);
- Scales uncertainties to 90% confidence level;
- Obtains depth-phase depth via depth-phase stacking (Murphy and Barker, 2006);
- Calculates location quality metrics for various distance ranges;
- Provides robust network magnitude estimates with uncertainties.

In 2010 we will test and validate the new location algorithm. Location improvements will be demonstrated by relocating some 7,000 ground truth events from the IASPEI Reference Event List (Bondár and McLaughlin, 2009b) and presented to the ISC Executive Committee and the ISC Governing Council. We expect that the ISC locations obtained by the new location algorithm will match or surpass the accuracy of the EHB locations. In order to maintain the homogeneity and consistency of the ISC bulletin, it would be advisable to relocate the entire 50+ years of ISC bulletin with the new location algorithm. Finally, the code of the ISC location algorithm, along with proper documentation, will be made openly available at the ISC website.

Bondár, I. and K. McLaughlin, Seismic location bias and uncertainty in the presence of correlated and non-Gaussian travel-time errors, *Bull. Seism. Soc. Am.*, **99**, 172-193, 2009a.

Bondár, I. and K. McLaughlin, A new ground truth data set for seismic studies, *Seism. Res. Let.*, **80**, 465-472, 2009b.

Dziewonski, A.M and F. Gilbert, The effect of small, aspherical perturbations on travel times and a re-examination of the correction for ellipticity, *Geophys. J. R. Astr. Soc.*, **44**, 7-17, 1976.

Engdahl, E.R., R. van der Hilst, and R. Buland, Global teleseismic earthquake relocation with improved travel times and procedures for depth determination, *Bull. Seism. Soc. Am.*, **88,** 722-743, 1998.

Kennett, B.L.N., E.R. Engdahl, and R. Buland, Constraints on seismic velocities in the Earth from traveltimes, *Geophys. J. Int.*, **122**, 108-124, 1995.

Murphy, J.R. and B.W. Barker, Improved focal-depth determination through automated identification of the seismic depth phases pP and sP, *Bull. Seism. Soc. Am.*, **96,** 1213-1229, 2006.

Sambridge, M. and Kennett, B.L.N., Seismic event location: non-linear inversion using a neighbourhood algorithm, *Pure Appl. Geophys.*, **158**, 241-257, 2001.

AUTOMATIC WAVEFORM MEASUREMENTS

Accurate hypocentre depth determination remains an acute problem in seismology. Surface reflections, if accurately picked, can provide precise depth estimates. Unfortunately, depth-phases are the most prone to phase identification and picking errors, which often leads to large depth errors.

Jointly with the CEA/DASE, France, we are running a project that aims to improve the accuracy of the ISC Bulletin event depths by gaining necessary information automatically from the waveforms widely available on-line. It is believed that taking this information consistently at many stations using the same technique has a chance to contribute to the Bulletin in the positive way, even when measurements are purely automatic.

For any given event, we calculate the envelope of the waveform at each teleseismic (20-90 degrees) station in a time window around the predicted first-arriving P and the largest possible moveout (pP – P time). We calculate the cepstrum for each trace, which allows us to determine if there is a depth phase present in the waveform. The cepstra are transformed into depth domain, using the depth-moveout relations predicted by ak135 at the epicentral distances of the stations, and then stacked to produce the summary cepstrum in depth domain. We show that the second largest peak of the stack represents a robust depth estimate derived from the entire network of recording stations.

In the remaining 1.5 years of the project we aim to test this technique and set up the automatic procedures that will determine depth of events that can be used during production of the Reviewed ISC Bulletin.

We also aim to make amplitude and period measurements consistent with the IASPEI magnitude standards, measuring SNR to be used in the phase weighting scheme during location as well as attempting to produce an additional set of automatic phase picks for events in the ISC Bulletin to be used for further research.

This project benefitted from a NEREIS grant for access to European Seismological Infrastructures that paid for a member of the ISC staff to travel and stay in France whilst working at the CEA/DASE.

PROJECTS

CTBTO LINK to the ISC DATABASE

Back in 2008, the UK Foreign and Commonwealth Office (FCO) has awarded the ISC with a three year grant to set up a dedicated and secure link to the ISC database for the CTBTO PTS and National Data Centres. The UK FCO provides 90% of the total required funding (£89,524) on the condition that four other relevant institutions from Nordic countries contribute remaining 10%. These institutions are GEUS (Denmark), NORSAR (Norway), FOI (Sweden) and University of Helsinki (Finland).

During 2009 we purchased and installed a dedicated server at the ISC premises that holds a mirror version of the ISC database. We set up a VPN Internet link to the computer systems of the PTS CTBTO and created comprehensive web-based software package to query the ISC database in ways specific to the monitoring community.

This software package allows for three types of bulletin searches: an area based, REB event based and an IMS station based search through the wealth of the parametric information in the ISC database. This software is being tested by members of the PTS staff.

It is anticipated that during 2010 and beginning of 2011 the PTS will consider the feasibility of supporting maintenance and further development of this system beyond this project.

FINANCE

The detailed financial statements of the ISC for 2009 were audited by Griffins, Chartered Accountants (Newbury, UK) and approved by Prof. John Woodhouse of ISC Executive Committee. These statements present the state of ISC's financial affairs as at 31 December 2009.

INCOME

In 2009, ISC had a total income of £ 578,289 from national contributions and sponsorship from Munich Re, a UK FCO grant and small contributions towards the FCO project from Norway, Sweden, Denmark and Finland. Interest on ISC bank accounts plus the income from selling ISC publications is also included. This amounted to just over 13% more than was budgeted and approved by the ISC Governing Council during their last meeting. In comparison with 2008, this was a 14.8% increase in total income. The exchange rate between the UK £ and USA $ steadily changed from £1=$1.46 at the start of the year to £1=$1.62 at the end of December.

During 2009, two more members joined the ISC Governing Council: the Earthquake Research Institute of the University of Tokyo, Japan who contributed **5 units** and Red Sismica de Puerto Rico with **1 unit**. The India Meteorological Department generously raised their contribution **from 1 unit to 15**. China Earthquake Administration (CEA) raised its contribution **from 15 to 20 units**. The Commissariat a l'Ernergie Atomique (CEA/DASE), France also increased its contribution **from 1 to 2 units**. At year-end, after 3 consecutive years the membership fees from CALTECH, USA were unpaid and written off as bad debts.

EXPENDITURE

More than 80% of ISC expenditure in 2009 was committed to personnel costs some £38,460 more than in 2008. During the year we welcomed three new seismologists, Elizabeth Robertson from New Zealand arrived in March to replace Przemas Kowalski and then Emily Delahaye from Canada, and Shengzao Chen from China (via Canada and USA) arrived in September to take over from Baokun Li who returned to China. The personnel costs include salaries, pension contributions, and recruitment and repatriation of new and departing staff. The ISC salaries follow the UK academic salary scales.

In accordance with the wishes of the ISC Governing Council the name of the Computer Replacement Fund was changed to the Contingency Fund, to reflect the gradual reduction in the cost of computers that the ISC requires. The Fund was reduced from £51,788 to £35,331 by assigning some of the expenditure on asset purchases such as new office lighting and central heating. Travel expenditure in 2009 was £2,660 greater than the previous year but once again, it should be noted that much of this travel resulted in either additional data or additional funding and often both, as well as promotion of the ISC to new audiences.

RESERVES

The gain in income over expenditure for 2009 was £83,064. ISC total reserves, comprising the cash in the bank, building and land, the money owed to ISC (debtors) minus the money ISC owes (creditors and remaining mortgage on the building) increased during 2009 to £497,358. The ISC Contingency Fund lessened during 2009 by £16,457 representing purchases made. The ISC General Reserve of £462,027 is equivalent to almost 12 month's operation of the ISC. This is well within British guidelines for charitable organizations.

CASH FLOW

The cash flow on Fig. 15 shows receipts and outlays using dates when transactions were recorded at the bank and the bank balances with US Dollars converted to Sterling using the exchange rate as of the end of each month.

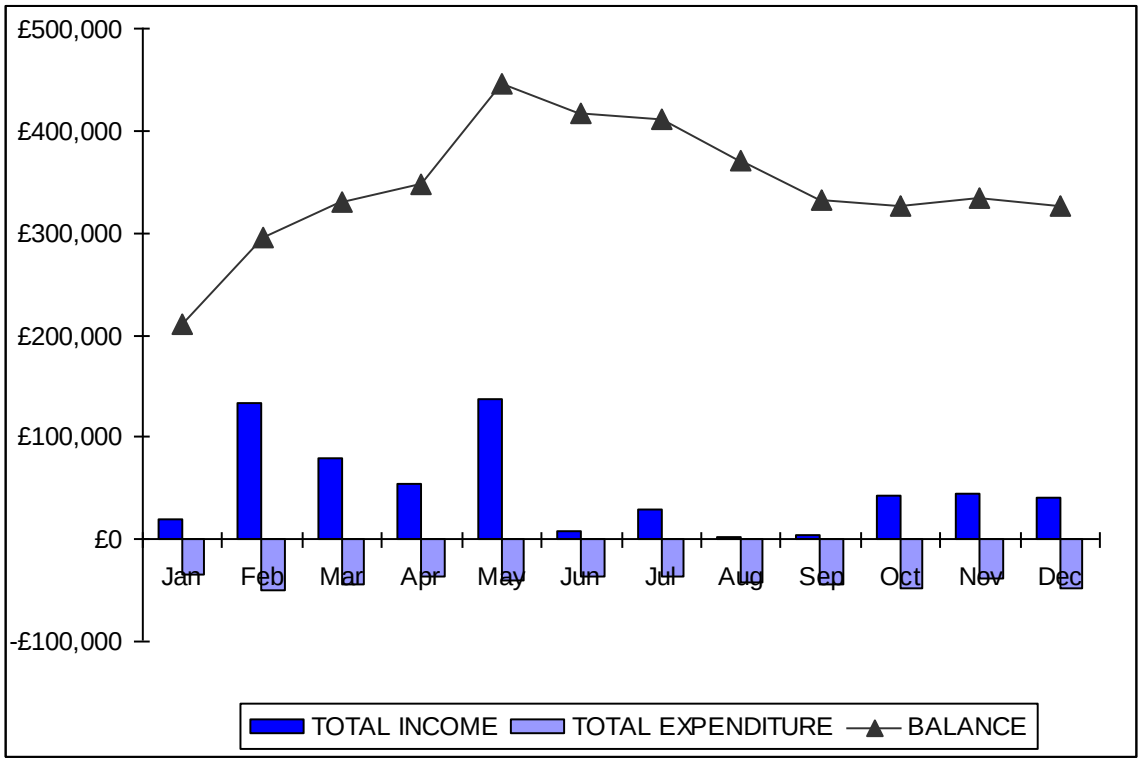

Figure 15. Income/Expenditure cash flow and cash balance

SCIENTIFIC LIAISONS

VISITORS to the ISC

The following geophysicists visited ISC premises in Thatcham during the year:

- Paul Richards – Lamont-Doherty Earth Observatory, Columbia University, USA
- Reinhard Mittag – Seismological Observatory Berggieshubel, Bergakademie Freiberg, Germany
- John Adams – Geological Survey of Canada
- Kevin Fenaughty – GNS, New Zealand
- David Bowers – AWE Blacknest, UK
- Jeffrey Given – IDC/CTBTO, Vienna, Austria
- Robert Pearce – IDC/CTBTO, Vienna, Austria

CONFERENCES, MEETINGS, WORKSHOPS

Members of the ISC staff or the ISC Executive Committee gave talks or presented posters at the following conferences, meetings and workshops:

- IASPEI General Assembly, Cape Town, South Africa
- GEM Outreach meeting, Munich, Germany
- GEM Historical catalogue coordination workshop, Pavia, Italy
- Frontiers of Seismology meeting, Edinburgh, United Kingdom
- SSA meeting, Monterrey, United States
- CTBTO International Scientific Studies meeting, Vienna, Austria
- China Cross-Straits Symposium, Fuzhou, China
- International Seismology School, Listvyanka, Russia
- MRR meeting, Tucson, United States
- NEIC-ISC-EMSC Coordination meeting, Golden, United States
- RELEMR meeting, Lisbon, Portugal
- CTBTO Data Mining workshop, Vienna, Austria
- International Workshop on earthquake Risk Reduction in the Northeast Asia Region, Beijing, China

ISC STAFF VISITING other INSTITUTIONS

Often with the help of the hosting institution, the members of the ISC staff visited and, where appropriate, gave a presentation to members of staff of:

- International Data Centre, CTBTO, Vienna, Austria
- Laboratoire de Detection et de Geophysique (LDG), CEA, Bruyères le Châtel, France
- China Earthquake Networks Center (CENC), CEA, Beijing, China

- Earthquake Administration of Fujian Province, China
- Geophysical Institute, Prague, Czech Republic
- National Science Foundation, Washington DC, United States
- IRIS, Washington DC, United States
- USGS, Reston, United States
- NEIC, Golden, United States
- SECED, London, United Kingdom
- Royal Society, London, United Kingdom
- Observatorio Sismologico y Geofisico del Suroccidente, Universidad del Valle, Cali, Colombia

ISC STAFF TRAINING

On the invitation of the IDC Director, Mr Lassina Zerbo, three members of the ISC editing team visited the premises of the IDC in May 2009. They spent two working days with several IDC analysts performing normal day-to-day duties. Valuable in-depth knowledge of IDC operations obtained during this training has helped the ISC editors in making informed decisions whilst reviewing the ISC Bulletin.

PhD STUDENTS at the ISC

Two PhD students, Louisa Tsang and James Bayliss worked at the ISC during the course of 2009.

Louisa Tsang has an MSc in Geophysics degree from Imperial College London. As part of her degree she spend a year at the University of California, Berkeley. Louisa asked about a work experience opportunity at the ISC during the summer months before starting her PhD course at the Department of Earth Sciences at the University of Hong Kong, working on the neotectonics of Tibet. Whilst at the ISC, Louisa studied earthquake locations in South-East Asia based on the newly received bulletin data.

James Bayliss has worked at the ISC in the past. He is the author of the bar-coding software that is still used by the ISC analysts to review the ISC Bulletin. James is currently working at the UK Office for National Statistics and also doing his PhD at the University of East Anglia (UK), supervised by Paul Burton. James's thesis is titled as "Seismicity and large earthquake potential in southwest Bulgaria and the conterminous Balkan high hazard region". James has benefitted from using ISC computers and software and was helped in his work by the ISC Systems and Database Administrator.

ISC PRIZE for OXFORD UNIVERSITY STUDENTS

The ISC has established a small annual Prize in Mathematics and Geophysics for a best first year student at the Earth Science Department of its home institution – the University of Oxford. The prize is given to the student with the best exam results in geophysics and mathematics. This year, Luke Sheldon and Cai Durbin were nominated to share the prize.

Each of them received the annual ISC Bulletin CD-ROM and a cheque for £100. In the past, we already had a precedent of the Oxford University student positively contributing to the ISC operations. By setting this prize the ISC hopes to attract Oxford University students to take note of the ISC services right from the first year, support the ISC in the future and perhaps even help the ISC in fulfilling its mission.

PAPERS PUBLISHED in 2009 that USE the ISC DATA

This list is a result of a special effort to put together a collection of scientific papers that used ISC or EHB data in an essential way in 2009.

The list is by no means complete. The ISC has become such a household name that many researchers fail to reference the ISC when using the ISC data.

We systematically looked through the journals with the high impact factor such as BSSA, JGR, GJI, PEPI etc. With rare exception, this list does not include papers published in journals with no electronic assess or search tools available.

Albaric, J., Déverchère, J., Petit, C., Perrot, J and Le Gall, B 2009 Crustal rheology and depth distribution of earthquakes: Insights from the central and southern East African Rift System. *Tectonophysics* **468**, 1-4, 28-41.

Allen, T.I., Marano,K.D., Earle,P.S.,and Wald, D.J. 2009 PAGER-CAT; a composite earthquake catalog for calibrating global fatality models *Seismol. Res. Lett.* **80** (1):57-62.

Atef A. H., Liu K. H., and Gao S. S. 2009 Apparent weekly and daily earthquake periodicities in the Western United States *Bull. Seismol. Soc. Am.*, **99**,4,2273-2279.

Balakina, L.M.and Moskvina, A.G. 2009 Characterization of the seismogenic process in the Aleutian island arc: II. The large earthquakes of February 4, 1965, and November 17, 2003, in the Rat Islands *Izv. Phys. Solid Earth* **45,** 3, 199-224.

Becker, R. H. & Sultan, M. 2009 Land subsidence in the Nile Deltal: inferences from rada infererometry. The Holocene**, 19, 6, 949-954.**

Beldjoudi,H., Guemache, M. A., Kherroubi A., Semmane, F., Yelles-Chaouche, A. K., Djellit, H., Amrani, A., and Haned, A. 2009 The Lâalam (Béjaïa, North-East Algeria) Moderate Earthquake (M_w = 5.2) on March 20, 2006 *Pure Appl. Geophys* **166,** 4, 623-640.

Belov, S.V., Shestopalov, I.P. and Khari, E.P. 2009 On the relation between endogenic activity of the Earth and solar and geomagnetic activity *Dokl. Earth Sci.* **428**, 1, 1142-1145.

Bondár, I. and McLaughlin K., 2009. A new ground truth data set for seismic studies. *Seism. Res. Let.*, 80, 465-472.

Bondo Medhus, A., Balling, N., Holm Jacobsen, B., Kind, R. & England, R. W. Deep-structural differences in southwestern Scandinavia revealed by P-wave travel time residuals. *Norw. J. Geol* **89,** 203-214.

Bonnardot, M-A., Régnier, M., Christova, C., Ruellan, E. and E. Tric 2009 Seismological evidence for a slab detachment in the Tonga subduction zone *Tectonophysics* **464**, 1-4, 20 84-99.

Bormann, P., Ruifeng, L., Zhiguo, X., Kexin, R., Liwen, Z.and Wendt, S. 2009 First application of the new IASPEI teleseismic magnitude standards to data of the China National Seismographic Network *Bull. Seismol. Soc. Am.*, **99**, 3, 1868-1891.

Braun, J., Burbidge,D. R. Gesto F. N., Sandiford M., Gleadow A. J. W., Kohn B. P. and Cummins P. R. Constraints on the current rate of deformation and surface uplift of the Australian continent from a new seismic database and low-T thermochronological data *Aust. J. Earth Sci*. **56,** 2, 99 – 110.

Burdick, S, van der Hilst, R. D., Vernon, F. L., Martynov, Vl, Cox, T, Eakins, J, Mulder, T, Astiz, L, and Pavlis, G. L. 2009 Model Update December 2008: Upper Mantle Heterogeneity beneath North America from P-wave Travel Time Tomography with Global and USArray Transportable Array Data *Seismol. Res. Lett.* **80**:638-645.

Bus, Z., Grenerczy, Gy., Tóth, L. and Mónus,P. 2009. Active crustal deformation in two seismogenic zones of the Pannonian region — GPS versus seismological observations *Tectonophysics*, **474,** 1-2, 343-352.

Choy, G.L. and Boatwright, J. 2009 Differential Energy Radiation from Two Earthquakes in Japan with Identical M_w: The Kyushu 1996 and Tottori 2000 Earthquakes Bull. Seismol. Soc. Am. 99, 3, 1815-1826.

Chu, Risheng and Zhu, Lupei and Helmberger, Don V. 2009 Determination of earthquake focal depths and source time functions in central Asia using teleseismic P waveforms. *Geophys. Res. Lett*. **36** .

Diehl, T., Kissling, E., Husen, S. & Aldersons, F. (2009), 'Consistent phase picking for regional tomography models: application to the greater Alpine region', *Geophys. J. Int.* **176**.

Ebel J. E. 2009 Analysis of aftershock and foreshock activity in stable continental regions; implications for aftershock forecasting and the hazard of strong earthquakes *Seismol. Res. Lett.* **80,** 4, 1062-1068.

Faenza, L.,Hainzl, S. and Scherbaum, F.2009 Statistical analysis of the Central-Europe seismicity *Tectonophysics* **470,** 3-4,195-204.

Frank, S. D., Foster, A. E., Ferris, A. N., and Johnson, M.. 2009 Frequency-Dependent Asymmetry of Seismic Cross-Correlation Functions Associated with Noise Directionality, *Bull. Seismol. Soc. Am.* **99**, 1, 462-470.

Frohlich, C., and Nakamura Y. 2009 The physical mechanisms of deep moonquakes and intermediate-depth earthquakes: How similar and how different? *Phys. Earth Planet. In.* **173**, 3-4, 365-374.

Fukuyama, E., Ando,R., Hashimoto, C., Aoi, S. and Matsu'ura M. A physics-based simulation of the 2003 Tokachi-oki, Japan, earthquake to predict strong ground motions *Bull. Seismol. Soc. Am.* **99,** 6, 3150-3171

Gusman, A.R. and Tanioka, Y. 2009 Analysis of the Tsunami Generated by the Great 1977 Sumba Earthquake that Occurred in Indonesia Bull. Seismol. Soc. Am. 99, 4, 169-2179.

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Hayes, G.P. & Wald, D.J., 2009. Developing framework to constrain the geometry of the seismic rupture plane on subduction interfaces a priori – a probabilistic approach, *Geophys. J. Int.* **176**, 951-964.

Hong, T-K and Kang**,** T-S. 2009 Pn travel-time tomography of the paleo-continental-collision and rifting zone around Korea and Japan. *Bull. Seismol. Soc. Am.* **99**, 1, 416-421.

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Lo, X., Cai, C., Yu, C. and Ning, J. 2009 Intermediate-depth earthquakes beneath the Pamir-Hindu Kush region: Evidence for collision between two opposite subduction zones Earthquake Science 22, 6, 659-665.

Neri G., Orecchio, N., Totaro, C., Falcone G., and Presti D.2009 Subduction beneath southern Italy close the ending; results from seismic tomography *Seismol. Res. Lett.* **80**(1):63-70.

Obayashi, M., Yoshimitsu, J., Fukao, Y., 2009. Tearing of stagnant slab, *Science* **324,** 1173.

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Ristau, J. 2009, 'Comparison of Magnitude Estimates for New Zealand Earthquakes: Moment Magnitude, Local Magnitude, and Teleseismic Body-Wave Magnitude', *Bull. Seismol. Soc. Am.* **99**(3), 1841.

Shomali, Z. H., and Roberts R.G. 2009 An application of relative moment tensor inversion to the 26 December 2003 M_w 6.6 Iran-Bam earthquake *Bull. Seismol. Soc. Am.* **99**:159-171.

Shuler, A., and Ekstrom, G. 2009 Anomalous earthquakes associated with Nyiragongo Volcano: Observations and potential mechanisms *J. Volcanol. Geotherm. Res*. **181,** 3-4, 219-230.

Steck, L.K., Phillips, W.S., Mackey, K., Begnaud, M.L., Stead, R.J., Rowe, C.A., 2009. Seismic tomography of crustal P and S across Eurasia. *Geophys. J. Int.*, **177**, 81-92.

Tajima, F., Katayama, I and Nakagawa, T. 2009 Variable seismic structure near the 660 km discontinuity associated with stagnant slabs and geochemical implications *Phys. Earth Planet. In.* **172**, 3-4, 183-198.

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Thingbaijam, K. K. S., Chingtham, P. and Nath, S. K. 2009 Seismicity in the North-West Frontier Province at the Indian-Eurasian Plate convergence *Seismol. Res. Lett* **80,** 4, 599-608.

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Wang, Z., Fukao, Y, Zhao, D., Kodaira, S.,. Mishra, O.P and Yamada,A. 2009**.** Structural heterogeneities in the crust and upper mantle beneath Taiwan *Tectonophysics* **476**, 3-4, 460-477.

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Zhang, Q., Sandvol, E. & Liu, M. (2009), 'Tomographic Pn Velocity and Anisotropy Structure in the Central and Eastern United States', *Bull. Seismol. Soc. Am.* **99** (1), 422.

Zhao, D., 2009. Multiscale seismic tomography and mantle dynamics. *Gondwana Res.* **15**, 297-323.

SUMMARY OF ACHIEVEMENTS

- Considerable additional Member's support secured for further development.
- EHB bulletin is re-accommodated within the ISC Bulletin and also distributed by the ISC along with station arrivals.
- Substantial progress is made on the project of providing the Link for CTBTO PTS and NDCs to the ISC database.
- Interactive ISC Bulletin Selection Tool was introduced on the ISC website.
- Provisional bulletin data are now collected from many data centres around the world within days/weeks after event occurrence; these are grouped and distributed to the outside world next day after submission as part of the preliminary ISC Bulletin.
- Three new Bulletin editors have been trained without considerable loss of the publication schedule.
- Work has continued on improvement of the ISC location procedures as well as on using automatic waveform analysis to constrain event depth.
- NSF and GEM proposals have been submitted following large scale preparation work.
- Finances substantially improved with further funds raised for the development of the interactive editing tool, further improvement of the entire ISC Bulletin and introduction of new services and products.
- Essential work on the ISC building was completed without an interruption to services.

Signed, June 10, 2010

Dr Dmitry A Storchak
Director